IMAX (Isotope Matter-Antimatter Experiment)

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ABSTRACT

The Isotope Matter-Antimatter Experiment (IMAX), a balloon-borne magnetic rigidity spectrometer designed to measure the cosmic ray abundances and spectra of antiprotons, hydrogen isotopes, and helium isotopes, was successfully flown from Lynn Lake, Manitoba, Canada on July 16-17, 1992. Duration at float was 16 hours at an average altitude of 36 km. About 1.4×10^6 events were recorded during ascent and over 3.4×10^6 events were recorded at float. In this paper, an overall description of the instrument and a preliminary evaluation of its performance are presented.

1. INTRODUCTION

IMAX was designed to measure cosmic ray antiprotons and light isotopes over an energy range from about 200 MeV/nucleon to 3 GeV/nucleon. This energy range includes the intensity maximum in the light isotope spectra. In the 1 to 3 GeV energy range, differences from the antiproton spectral shape and intensity expected from interactions of cosmic rays with the interstellar medium may indicate that antiprotons from "exotic" sources are present. This region was first explored by Bogomolov and his collaborators (Bogomolov *et al.*, 1987). The statistical accuracy of the IMAX antiproton flux measurements in this energy range will be over an order of magnitude better than those obtained in previous measurements. In addition, the IMAX data will be used to conduct a search for antihelium at a level at least comparable to the best current measurements.

IMAX uses the velocity of the incident particle to discriminate between antiprotons and background contamination from electrons and negative mesons. For isotopic measurements, mass identification is by the velocity vs. magnetic rigidity technique, supplemented at lower energies by ionization energy loss vs. magnetic rigidity.

In addition to its main goals, IMAX carried out a search for possible dark matter candidates using signals from the four IMAX scintillator layers in conjunction with a self-triggering time-of-flight system (McGuire and Bowen, 1993).

2. INSTRUMENT DESCRIPTION

A schematic drawing of the IMAX instrument is shown in Figure 1. IMAX had a useful geometry factor of 140 cm^{2}sr. As its basis, IMAX used the NASA/NMSU Balloon-Borne Magnet Facility payload, with additional detectors and electronics supplied by the collaboration. Additional details of the IMAX detectors are presented in these conference proceedings.

The IMAX magnetic rigidity spectrometer consists of two independent systems for trajectory determination. These employed drift chambers (DC) and MWPCs located in the high field region of a (61 cm diameter) single-coil superconducting magnet. A description of the magnet and MWPC system can be found in Golden *et al.* (1978 and 1991). Eight MWPC layers were used, three above the top DC, three at the center of the magnet between the DCs, and two below the lower DC.

The DC system consisted of two chambers, each containing ten layers (six in the principal bending plane) of hexagonal drift cells (Hof *et al.*, 1993; Menn *et al.*, 1993). Preliminary analysis of the DC system shows that, independent of the strength or direction of the magnetic field, each cell has an average position resolution of about 100 μm and near 100% efficiency. All 320 cells in the DC system were operational throughout the flight. The characteristic maximum detectable rigidity (MDR) from the DC system alone at this stage in the analysis is 175 GV/c for Z=1 particles and 250 GV/c for He. Analysis of the MWPC system is ongoing.

Particle velocities are obtained from a high-resolution time-of-flight system (TOF), a Teflon Cherenkov counter (C1), and two silica-aerogel Cherenkov counters (C2 and C3). The time-of-flight scintillators and two additional scintillators (S1 and S2) located between the time-of-flight layers give four independent measurements of particle charge and ionization energy loss.

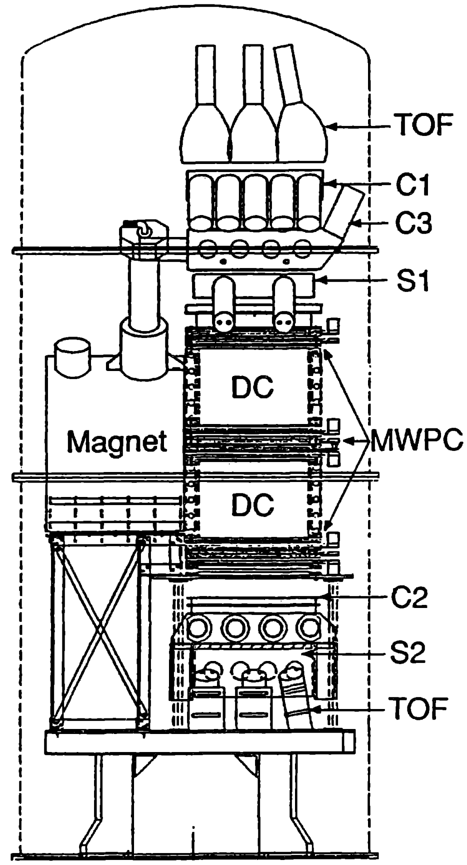

FIGURE 1: The IMAX Payload

The TOF system (Mitchell *et al.*, 1993) was also used to form the first level event trigger. Analysis of the timing performance of the TOF system is at a preliminary stage. With only first order position corrections and no time-walk corrections, timing resolutions of 130 ps for Z=1 particles and 105 ps for helium have been obtained. The flight path between the upper and lower TOF planes is 2.5 m in length.

The C1 Cherenkov counter supplements the TOF velocity measurement between about 0.5 and 1.0 GeV/nucleon. This detector used two 56 cm x 54 cm x 1 cm layers of Teflon (n=1.33), located in a light integration box viewed by ten 3 inch diameter Hamamatsu R1307 PMTs. In bench testing, 36 photoelectrons were obtained from this counter for β=1, Z=1 particles. The flight performance of C1 has not yet been assessed.

Initial evaluation of the two silica-aerogel (n=1.055) Cherenkov counters (Labrador *et al.*, 1993) indicate that C2 yielded approximately 13 photoelectrons and C3 yielded 15 photoelectrons for a β=1, Z=1 particle. Background noise, mainly from the PMTs, limits the threshold that can be set for determining whether an incident particle produced light in the Cherenkov radiator as a part of the background rejection for antiproton measurements. This was measured on the ground by using "random" triggers both at room temperature and at a temperature of over 40 °C. In the worst case, the total average noise from C2 and C3 was less than one photoelectron.

S1 and S2 used light integration boxes and plastic scintillators. S1 contained a 51 cm x 51 cm x 1 cm scintillator, viewed by four Hamamatsu R1307 PMTs. S2 used a 55 cm x 49 cm x 1.8 cm scintillator, viewed by twelve Hamamatsu R2409-01 high-field 2 inch diameter PMTs.

The IMAX trigger required a four-fold coincidence between PMTs on the top and bottom TOF planes. The coincidence level could be reprogrammed in flight. The analog delays between the PMTs or amplifiers and the ADCs were constructed using solid state delay lines for all counters except the TOF. This resulted in a considerable weight savings over traditional delay cables.

3. FLIGHT

The IMAX flight took place on July 16-17, 1992, from Lynn Lake, Manitoba, Canada. Float was reached about 7 hours after launch. The instrument took data throughout ascent, recording about 1.4×10^6 events. These data will be used to determine altitude-dependent particle spectra. Float duration was 16 hours at an average altitude of 36 km, with an atmospheric overburden of less than 5 gm/cm^2. At the end of the float period, the magnet was ramped down and data was taken with the magnet off in order to check the alignment of the tracking chambers. Landing was near Peace River, Alberta, Canada, with the instrument being recovered in excellent condition. All payload and detector systems appear to have performed well throughout the flight. Over 3.4×10^6 events were recorded during the float period.

4. EXPECTED RESOLUTION

A major goal of IMAX was to measure the spectrum of cosmic ray antiprotons over an extended energy range. The MDR of the IMAX spectrometer is sufficient to clearly separate positive and negative curvature trajectories throughout the rigidity range of interest, so no significant background is expected from "spill-over" of protons. Thus, at altitude, the main background to the antiproton measurements comes from electrons and negative muons. While the background/antiproton ratio varies with rigidity, we require that the instrument should be able to reject the electron and negative meson components to a level of at least 10^{-4}. Figure 2 shows the nominal ability of IMAX to distinguish a muon from an antiproton, as a function of rigidity, using the TOF system and the aerogel Cherenkov counters. This is based on an analytic calculation using preliminary results from post-integration ground tests and from flight data. The nominal ability of IMAX to reject electrons is at least as good as indicated by Figure 2, since the Cherenkov counters are effective at lower rigidities.

The curves in Figure 2 are based on an effective discrimination threshold of one photoelectron in each of the Cherenkov counters. The rejection power of each counter is the Poisson probability of the mean Cherenkov signal from a muon at a given rigidity fluctuating below this threshold so that the muon is misidentified as a proton. Above the antiproton threshold in the aerogel, the rejection power has been calculated as the probability of the muon signal fluctuating downward to within two sigma of the expected antiproton signal. The total rejecting power is the product of the individual contributions. This figure shows that IMAX will be able to clearly separate antiprotons from background to a rigidity of over 3.2GV/c.

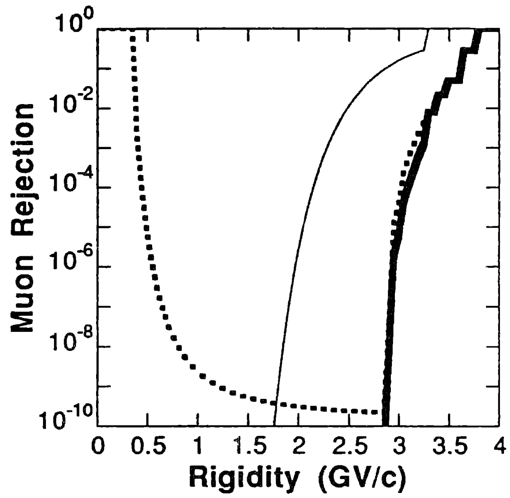

FIGURE 2: Nominal IMAX background rejection for antiproton measurements. Shown are the contributions from C2/C3 (dotted) and TOF (light solid) as well as the total (solid).

The ability of the IMAX instrument to separate isotopes is illustrated in Figure 3, which shows the expected mass resolution for ^{4}He calculated using an analytic simulation of the velocity vs. rigidity method. Preliminary resolution values obtained from post-integration ground tests and from flight data were used in the simulation. Included in the figure are the individual contributions of the spectrometer and velocity measuring systems, as well as the expected degradation in resolution due to multiple coulomb scattering in the spectrometer. Requiring a minimum 0.25 amu mass resolution to separate ^{3}He from ^{4}He, IMAX will cover a range from geomagnetic cutoff (about 200 MeV/nucleon) to 1.2GeV/nucleon using the velocity measurements from the TOF. A second region from 2.0 GeV/nucleon to about 2.8 GeV/nucleon will be covered using velocities measured by C2 and C3. It is anticipated that continued analysis will yield resolutions from the TOF and Cherenkov counters which exceed the preliminary values used in Figure 3. In addition, the final mass resolution of IMAX will include a contribution from the ionization energy loss vs. rigidity method, which is effective for He at energies up to about 1 GeV/nucleon. As a result, the final mass resolution should be better than indicated by Figure 3.

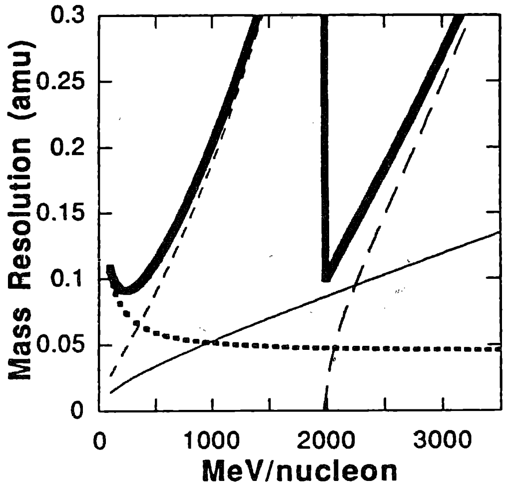

FIGURE 3: IMAX mass resolution for ^{4}He. Shown are components from rigidity (light solid), multiple scattering (dotted), TOF (short dashed) and C2/C3 (long dashed) along with the overall resolution (solid).

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